

Dark Matter Balls Help Supernovae to Explode

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Abstract

As a solution to the well-known problem that the shock wave potentially responsible for the explosion of a supernova actually tends to stall, we propose a new energy source arising from our model for dark matter. Our earlier model proposed that dark matter should consist of cm-large white dwarf-like objects kept together by a skin separating two different sorts of vacua. These dark matter balls or pearls will collect in the middle of any star throughout its lifetime. At some stage during the development of a supernova the balls will begin to take in neutrons and then other surrounding material. By passing into a ball nucleons fall through a potential of order 10 MeV, causing a severe production of heat - of order 10 foe for a solar mass of material eaten by the balls. The temperature in the iron core will thereby be raised, splitting up the iron into smaller nuclei. This provides a mechanism for reviving the shock wave when it arrives and making the supernova explosion really occur. The onset of the heating due to the dark matter balls would at first stop the collapse of the supernova progenitor. This opens up the possibility of there being *two* collapses giving two neutrino outbursts, as apparently seen in the supernova SN1987A - one in Mont Blanc, and one 4 hours 43 minutes later in both IMB and Kamiokande.

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1 Introduction

A supernova explosion is supposed to originate from in-falling material of the progenitor-star being reflected after having been stopped by the nuclear forces, when a neutron star is first formed and compressed to about double nuclear matter density [1, 2, 3]. The re-expansion of the compressed neutron star in the center would then cause a shock wave to propagate outward. This shock wave is expected to cause what is seen as the supernova explosion. However, more detailed calculations suggest that, at least unless one includes convective or non-symmetric development, the shock wave tends to stall before reaching out far enough to expel the stellar envelope and provide sufficient energy for the observed magnitude of supernova explosions.

This conclusion that an insufficient amount of energy is deposited into the material expelled from the core remains true, even when the effect of a flux of neutrinos from the center is included in the calculations. Heating from these neutrinos does though not revive the shock wave sufficiently to provide the energy of 1 foe $\equiv 10^{51}$ ergs needed by the observed stellar remnants and radiation. It is not that there is insufficient energy available in the collapse, because the gravitational collapse to the neutron star easily releases 100 foe. Nevertheless the simulations show that the shock wave emitted runs out of force and cannot even provide the one foe needed [4].

It is still hoped that more detailed two dimensional or three dimensional simulations including convection could explain how, at least in some direction, enough energy would be brought to revive the shock wave so as to provide the observed explosion [5]. Alternatively some extra source of energy providing this “revival” could help [6].

It is indeed such an *extra* energy source, which we propose in the present article. In section 2 below we shall describe our special model [7, 8, 9] for dark matter, which has the peculiar property that it can unite with ordinary matter and thereby release an energy of the order of 10 MeV per nucleon. In fact one should think of our dark matter as consisting of pearls of cm-size with an interior in which there is a different type of vacuum. When nucleons penetrate into this new type of vacuum, it is supposed that they pass a potential barrier so as to release for heat production about 10 MeV per nucleon. It should, however, be noticed that these pearls are supposed to be surrounded by a thin region in which there is an electric field preventing say protons and, even more so, heavier nuclei from penetrating into the pearls. So *only* when the protons or the nuclei have got sufficiently high temperature to pass this electrical field will the pearls begin to take them up from the surrounding material. Neutrons, however, may be able to penetrate even at low temperature.

In the following section 2 we shall review our model for dark matter as being some very heavy pearls, with a mass of about 10^8 kg per cm-size pearl. In section 3 we then give the scenario for the development of a core collapsing supernova, with special emphasis on the activity of our dark matter pearls.

In subsection 3.2 we provide an estimate of the time between the first collapse of the iron core, which is interrupted by the ignition of our pearls, and the second final collapse. The importance of this time difference is that apparently *two* neutrino outbursts were observed in the supernova SN1987A, with a time difference of 4 to 5 hours.

Finally in section 4 we conclude and resume.

2 Our Dark Matter Model

Usually it is believed that dark matter must result from physics beyond the Standard Model, e.g. WIMPs [10] usually identified as the lightest SUSY partner of the known particles. Although ATLAS and CMS have looked for SUSY partners, they only found lower limits for their masses [11]. Also claims for direct detection of WIMPs [12, 13, 14] are in contradiction with experiments not having seen any [15, 16, 17]. We have, however, for some time been working on a model [7, 8, 9] for the dark matter, which does *not need an extension of the Standard Model with new fundamental particles*. Rather we propose in our model, as new physics, *only* some bound states composed of 6 top and 6 anti-top quarks bound together mainly by Higgs-forces already present in the Standard Model itself. It should though be admitted that we supplement the Standard Model with a fine-tuning principle, the “Multiple Point Principle” [18, 19, 20], which is defined to mean that the coupling constants in the Standard Model are adjusted so as to arrange for several - in fact we think 3 - different vacua to have just the same energy densities. The existence of one of these speculated vacua led us to the *prediction* of the Higgs mass [21]. The existence of another such speculated new vacuum is supposed to lead to the adjustment of mainly the top-Yukawa coupling, so as to make 6 top plus 6 anti-top quarks bind very strongly together and form a relatively very light bound state [22, 23, 24, 25]. Furthermore, according to our “Multiple Point Principle”, a vacuum is supposed to form containing a condensate of this bound state and having the same energy density as the vacuum in which we live.

The idea of our model for dark matter is now that the dark matter floating around in space consists of small pearls of cm-size, inside which is a bubble of the bound state condensate vacuum. Between the two different types of vacua there will be a skin - a surface tension one could say - of a rather high density (because its order of magnitude is give by the scale of weak interactions) $S \sim 4 * 10^8 \text{ kg/m}^2$. In order that such a bubble be stabilized it has to be pumped up with some material under sufficiently high pressure to resist the pressure from this skin. In our pearls making up the dark matter this pressure is about $5 * 10^{27} \text{ N/m}^2$, and the interior of the pearl is much like a little white dwarf star with a density of ordinary matter inside it of the order of $10^{14} \text{ kg/m}^3 = 10^{11} \text{ g/cm}^3$. A typical ball has a radius of 0.67 cm and mass of order 10^8 kg . We note that our dark matter balls are too light for observation by microlensing [26, 27, 28]. In order to keep the ordinary matter inside the pearls from expanding out, it is crucial that a nucleon feels a potential difference in passing through the skin such that its potential inside the pearls is lower by about 10 MeV than outside. In fact we estimated the potential difference to be $\Delta V = 10 \pm 7 \text{ MeV}$.

It is this potential difference of 10 MeV that is crucial for our idea of using our pearls to help the supernovae to truly explode. This potential difference means that an energy of 10 MeV per nucleon is released, whenever a nucleon is brought inside one of our pearls. Now, however, this transport of nucleons into the interior of the pearls is prevented, because these pearls are normally surrounded by an electric field repelling protons as well as nuclei. This field is there due to the fact that, analogously to white dwarfs, the pearls contain degenerate electrons. We expect our typical pearls to contain a degenerate Fermi sea of electrons with a Fermi energy of the order of 10 MeV. While now the protons

are kept inside the skin by the potential difference mentioned above, the Fermi sea of electrons will spill over to the outside of the skin region. Thus, in a little range of order 20 fm outside the skin, there are electrons - but no protons. This gives rise to an electric field in much the same way as there is an electric field inside an atom, due to the protons in the nucleus being charge-wise compensated only by the electrons, which are placed appreciably further out. It is the electric field around the pearls, which prevents protons and/or nuclei from penetrating into the pearls. They have first to tunnel or otherwise pass through this electric field, before they can be caught by the nuclear potential of the 10 MeV which we have hypothesized. If the pearl gets bigger than our typical radius of 0.7 cm the electric field layer gets thicker, with a thickness proportional to the fourth root of the pearl radius; but at the same time the electric field strength becomes smaller the bigger the radius and the potential for passing the electric field layer varies as the inverse of the fourth root of the radius. Thus it gets easier for a positively charged particle (proton or nucleus) to penetrate into the ball, as the ball grows in size.

We take the size of typical pearls to be close to the critical point for collapse under their pressure against the assumed 10 MeV potential difference across the skin. Then, taking the dark matter density in our galaxy to be 0.3 GeV/cm^3 , we estimate that the earth is hit by one of our pearls about once every 200 years, matching with the assumption that the famous Tunguska event [29] was caused by the fall of such a pearl [9]. An impact rate of one pearl per 200 years means that the earth should have been hit by $2 * 10^7$ pearls in its history. Correspondingly then the sun should have been hit by $2 * 10^7 * (R_{sun}/R_{earth})^2 = 2 * 10^{11}$ pearls. Since each pearl has a mass of 10^8 kg , this means that the sun should have collected $2 * 10^{19} \text{ kg}$ of dark matter, which is 10^{-11} times the mass of the sun. The supernova SN1987A was supposedly about 20 times heavier than the sun [30], when it exploded. Taking the variation of the radius and lifetime of a main sequence star to vary respectively like $R_{MS} \propto M^{0.78}$ and $\tau_{MS} \propto M^{-2}$, we get $R_{MS}^2 \tau_{MS} \propto M^{-0.5}$. Thus $0.5 * 10^{11}$ pearls should have collected in the SN1987A, with a collected mass of $0.5 * 10^{19} \text{ kg}$, which is 10^{-13} times the mass of the supernova.

3 Scenario of Supernova Collapse

During mainly the main sequence development of the supernova-star the dark matter pearls in our model fall into the star, where they get stopped and then fall essentially to the center of the star. One should have in mind that our pearls have densities of the order of 10^{14} kg/m^3 . At the relatively low temperature of $10^7 \text{ K} \approx 1 \text{ keV}$ in the center of the star, during its main sequence development, neither protons, other nuclei nor the pearls themselves can pass through the electric field¹ surrounding a pearl with a potential difference typically of the order of 10 MeV. So at this time the pearls are quite inert.

¹As in our previous article [9] we assume that the typical pearls making up the dark matter have such a size that they are just on the borderline of stability, where their protons would escape and the pearls would collapse. In this case, the proton would have to just pass the total potential difference for getting in or out of the pearl. Now we already assumed that there is a potential drop of 10 MeV on passing through the skin of the pearl. Thus, in order to make the *total* potential difference for the proton in passing from inside to outside the pearl zero, the electric potential has also to be 10 MeV. For pearls bigger than the “critical size” the electric potential difference will be smaller.

However, the pearls can begin to sip up material and expand, if the charged particles in the surroundings get so energetic/hot that they can penetrate the electric field and then gain energy from passing into the pearls through the skin. Alternatively free neutrons may become available and they can just pass through the electric field without problems, because they are neutral. In the actual supernova, it is the absorption of neutrons which becomes important first. This causes a very rapid expansion of the pearls after the silicon burning era when the supernova progenitor begins its Kelvin-Helmholtz gravitational collapse. The consequent huge deposition of energy of 10 MeV per absorbed nucleon halts the collapse of the star until the interior of the star cools down again. In this way we obtain a two stage gravitational collapse [31], with possibly an intense burst of neutrinos at each stage.

3.1 Absorption of Material by Balls

The speed v_{wall} with which the pearl skin or wall comes to move relative to the surrounding material is estimated in the following way:

It is only the neutrons that pass freely into the pearls. Supposing their number density (outside the pearls) is n_n and that their thermal speed is v_n ; then a layer of neutrons of thickness v_n penetrates into the pearl every time unit. Supposing now that the density of nucleons inside the pearls is in our model $10^{14} \text{ kg/m}^3 = 10^{11} \text{ g/cm}^3 \sim 6 * 10^{34} \text{ nucleons cm}^{-3}$, then the speed with which the pearl expands, without having to change its density, becomes

$$v_{wall} = v_n * \frac{n_n}{6 * 10^{34} \text{ cm}^{-3}} \quad (1)$$

For instance at the silicon burning time, when silicon burns into elements in the iron group, the temperature is of the order of $4 * 10^9 \text{ K} = 0.4 \text{ MeV}$ [1]. Thus the speed of say a neutron is then $\sqrt{3 * 0.4 \text{ MeV/GeV}c} = 5 * 10^{-2}c = 10^7 \text{ m/s}$. At this time the density is $3 * 10^7 \text{ g/cm}^3$ and, from Bodansky et al [32], the density of neutrons is given as $n_n = 10^{20} \text{ cm}^{-3} = 10^{26} \text{ m}^{-3}$. Thus the speed of the wall becomes $v_{wall} = 10^7 * 10^{26} / 6 * 10^{40} \text{ m/s} = 1.7 * 10^{-8} \text{ m/s}$. With the time scale taken as the one day it takes to pass through the silicon burning era, the skin would have moved just $0.9 * 10^5 * 1.7 * 10^{-8} \text{ m} = 1.5 \text{ mm}$.

Normally there is an electric field in a thin layer around a dark matter pearl pointing perpendicularly to the skin or the surface separating the two vacua. This is so because there is normally a difference in density - for instance of electrons - between the two sides of the surface. This electron density falls off gradually across the surface of separation, while the proton density typically changes very abruptly at the skin. The latter has a very small thickness compared to atomic physics scales. If the density variation of the electrons and the protons do not follow each other closely across the surface, an electric field will appear at this surface. If, however, the density of matter inside and outside our pearls would be the same, so that especially the density of electrons would be the same on the two sides, there would be no electric field.

Thus, once the density in the outside becomes of the order of the density 10^{14} kg/m^3 inside our pearls, the skin can move rather freely; it would do so with essentially the thermal speed of the particles. So, when the density in the surroundings becomes of this

order, the pearls would expand rapidly even without the need for any neutrons. Assuming that the density of the material at the center of the star is given by the relationship [3] $\rho = 10^6 T_9^3$, where T_9 is the temperature in units of $10^9 K$, our pearl-density is achieved for the temperature $T_9 = (10^{11} \text{ g/cm}^3 / 10^6)^{1/3} = 50$. Using instead the estimate of the temperature of star matter of density 10^{11} g/cm^3 given in [2, 33], we get $T = 1.21 \text{ MeV} = 1.2 * 10^{10} K$; this means $T_9 = 12$, which is four times smaller than our first estimate because it includes the effect of some decrease in entropy towards the core. So if we wait for even charged matter to be sipped up, it would start in the temperature range $T_9 = 12$ to 50.

But the presence of free neutrons in the surrounding matter becomes sufficiently copious at a lower temperature and causes a rapid development of the pearls, before the density gets sufficiently high for the absorption of charged particles. In fact the free neutron density becomes a few percent of the total star density for total densities of 10^{10} g/cm^3 and above [2, 33]. It follows that, when the total star density is of this order of 10^{10} g/cm^3 , neutrons are absorbed by the pearls with a significant rate for the supernova. In fact, from equation 1, the speed v_{wall} of the skin of the pearls relative to the surrounding material becomes of the order of 10^{-3} times the thermal speed. If the temperature now were say 1 MeV, then the thermal speed would be $\sim c/18$ and thus the speed of the wall would be $10^{-3} * 3 * 10^8 \text{ ms}^{-1} / 18 \sim 10^4 \text{ m/s}$, meaning that a region with radius of the order of 100 km would be passed in 10 s. So, under these conditions, the pearl would spread explosively in a few seconds.

This fast absorption might though be damped by the pearls picking up the neutrons and thus becoming damped in their expansion, until the previous neutron density in their neighborhood has been essentially re-established by nuclear statistical equilibrium in the star. The pearls cannot pick up the protons as long as there is an electric field present, which is expected to be there until the density is the same on both sides of the wall.

In spite of such possible damping effects, we still believe that the expansion of the pearls can easily become fast enough that we must consider the process explosive. Thus the whole region in which the absorption goes on gets strongly heated and essentially all the energy from the passage of the nucleons (as neutrons we suppose), each delivering 10 MeV, gets collected in such a region.

We expect the expansion to stop, when the density of the material surrounding the balls becomes sufficiently low.

3.2 Calculation of Time Interval between the Neutrino Emissions

When the explosive expansion of the pearls takes place, an energy of $10 \pm 7 \text{ MeV}$ per nucleon (the uncertainty is estimated in [9]) passing into the pearls is released. This will lead to a temperature increase in the region over which this released energy is getting distributed. Now a thermal energy of 10 MeV obtained by a nucleon will get distributed as ΔT for each degree of freedom. Thus at first it seems that the temperature will be raised by $\Delta T = 10 \text{ MeV} / 3 = 3 \text{ MeV}$.² We are interested in the mean excess temperature

²This estimate would be correct if the potential in the plasma for the nuclei were treated as a harmonic oscillator potential. If, however, we counted the particles as free particles only the kinetic energy would be

in the period until the released energy has been emitted out of the region by essentially neutrinos. The mean excess temperature can of course be at most half of the starting value. This means it will at most be $\Delta T = 10 \text{ MeV}/(3 * 2) = 1.7 \text{ MeV}$.

Let us imagine the situation just after the explosive expansion of the balls took place:

1. The pearls/balls have most likely united together in one big ball, with its center approximately coinciding with the center of the star.
2. Of course the interior of this united ball has been heated up by the extra temperature ΔT . But, in addition, there is a region outside - and thus above the ball - in which a similar temperature increase has been caused by the dark matter explosion. We may guess that this outside region, which is similarly heated, is of about the same mass as the united ball.
3. The explosion itself may have only taken say 10 seconds.
4. But now the cooling, by neutrinos mainly [34, 35], sets in. In first approximation this cooling rate is just given, as we shall see below, to be of the order of 10^{14} erg/g/s . However, it is likely that the cooling is a bit slower further away from the center than deeper down, because the density higher up in the core is somewhat lower. Also presumably most of the heat will be produced around the skin of the ball. Both these effects could easily lead to the central region reaching the temperature and pressure, where the Kelvin-Helmholtz gravitational collapse restarts, first.
5. The Kelvin-Helmholtz collapse restarts in the central region when the extra temperature ΔT has been cooled away by neutrino emission; we estimate below this cooling should take of the order of 14 hours. However the upper part of the region heated by pearl expansion and nucleon absorption will still remain somewhat heated up compared to the central region.
6. For instance, in this higher region, the iron peak nuclei could still be split into say nucleons or at least helium.

In order to estimate the cooling time for the excess temperature ΔT to be dissipated, we should estimate the ratio r of the total amount of matter significantly heated to the amount of matter sucked in by the pearls and finally contained in the big ball. Under point 2 in the list above we guessed that the amounts of matter heated inside and outside the ball were about the same. Taking the initial pearls to make up a negligible amount of mass, this means that we take the ratio r to be 2. Thus twice as many nucleons as at first thought are heated up and the temperature increase gets reduced by a factor of 2 compared to our first estimate above of $\Delta T = 1.7 \text{ MeV}$. This means we get the true temperature increase to be $\Delta T = 1.7 \text{ MeV}/r = 0.85 \text{ MeV}$.

Now we estimate the time it takes for the energy deposited from the explosion of the pearls to be lost by neutrino emission. Crudely we take the *excess temperature* ΔT to dominate the whole temperature. At the temperature of $\Delta T = 0.85 \text{ MeV} = 8.5 * 10^9 \text{ K}$,

non-zero and we would instead have argued for $\Delta T = 10 \text{ MeV}/(3/2) = 6 \text{ MeV}$ at this stage. Presumably ΔT lies in between 3MeV and 6 MeV.

and using the density 10^{10} g/cm³ from [2, 33], the rate of heat transport out of the region by neutrinos becomes [3, 34] 10^{24} erg/cm³/s, which translates into 10^{14} erg/g/s. Now we must count that a major part of the excess energy of 10 MeV/nucleon = $10 \text{ MeV} * 6 * 10^{23}/\text{g} = 10^{19}$ erg/g will have to be emitted in this way, but that some of the energy remains keeping the region above the ball somewhat hotter (see points 4 and 5). Perhaps part of the heat could even split the iron into nucleons and/or helium (point 6). Also some of the heat falls into the neutron star, because it does not manage to get out before the genuine collapse of the star takes place. Suppose we take that half the energy (per gram), i.e. $0.5 * 10^{19}$ erg/g, is properly emitted by the neutrinos. Then with the neutrino energy loss rate of 10^{14} erg/g/s, this will take $0.5 * 10^5 \text{ s} = 14$ hours. After this time relative to the ignition of the dark matter pearls, the star will restart its gravitational collapse.

Let us assume that the first attempt by the star to collapse after the silicon to iron burning era, which got stopped by the pearl explosions, was accompanied already by a significant neutrino burst that, in the case of supernova SN1987A, was observed by the LSD detector at Mont Blanc [36]. In our picture, this Mont Blanc neutrino burst was emitted just before our pearls exploded. Then we estimate, in a period of order 14 hours later, the heated interior of the star would cool down and the Kelvin-Helmholtz gravitational collapse would restart after this delay. This next collapse is supposed to be the main one responsible for the neutrino burst seen by Kamiokande and IMB [37, 38, 39] followed by the genuine emission of the supernova remnants. Both these neutrino bursts could have come from the very central part of the star - meaning distances from the center of the order of only a neutron star size of say 10 km. The neutrino emission during the 14 hours period, on the contrary, would be so weak that there would be no chance to see them experimentally on the earth.

Both the above neutrino outbursts involve large bunches of neutrinos, because they arise from the *deep* interior of the supernova. We expect the energies or the temperature of the neutrinos to be largest in the second of the two outbursts. Let us argue for this expectation using a basically oversimplified set of assumptions: Counting only the electron neutrinos, which are produced from the protons by picking up an electron from the degenerate gas of electrons and becoming a neutron plus a neutrino. Then, for material starting out with roughly similar amounts of protons and neutrons which end up as solely neutrons, the amount of neutrinos of this sort is just proportional to the number of nucleons. But now let us take the crude approximation that the radius of the resulting neutron star is only weakly dependent on the amount of matter in it. Then the potential energy released per nucleon in the first collapse of say a mass M_1 would be proportional to the average mass already fallen in during the falling period, which means proportional to $M_1/2$. However the energy released per nucleon during the fall in of the next clump of matter of mass M_2 say would be similarly proportional to $M_2/2 + M_1$. Thus the temperature ratio for neutrinos in the second collapse to that for those in the first would be $\frac{M_2/2 + M_1}{M_1/2} > 2$. For instance if $M_1 = M_2$, this ratio would mean that the second burst would deliver neutrinos with 3 times as large a temperature. The re-scattering or absorption and re-emission of neutrinos, which ends with them all coming from a certain “optical depth”, may smooth away part of this temperature difference. In fact the fits [31, 37, 38] to the Mont Blanc and Kamiokande observations of the first and the second

bursts of neutrinos give temperature estimates of 1 MeV and 4 MeV respectively.

The most remarkable coincidence supporting our whole model is that, in the case of supernova SN1987A, *two bunches* of neutrinos were indeed observed - one by the Mont Blanc experiment [36] and one by both Kamiokande [37, 38] and IMB [39] - with a time difference of 4 hours 43 minutes. Our 14 hours estimate for this time difference is off by a factor of 3. However the potential difference between the inside and outside of our dark matter pearls, $\Delta V = 10 \pm 7$ MeV, is uncertain by a factor of 3 and our whole estimate was anyway very crude. So we could not hope for better agreement.

3.3 Revival of the Shock Wave

After the second collapse of the star the main effect of our dark matter pearls will have disappeared. *However a region mainly a few hundred kilometers away from the very center has been heated up significantly by the explosion of the pearls.* In this region the Fe peak materials will even have split into nucleons or into helium say. The gravitational fall of the core matter into the center causes a compression to twice nuclear matter density in a contracted proto-neutron star object. The highly contracted proto-neutron star rebounds and very strongly expels the matter around it. This causes the usually expected shock wave to appear, below which the matter moves outward and above which the matter falls down. Now the usual problem with models for supernova explosions is that detailed estimates of the propagation of the shock wave indicates that the shock wave stalls - at least in “one-dimensional”, i.e. rotationally symmetric, models. This means the shock wave does *not* come out of the iron core and fails to produce the energy needed to deliver an outburst of supernova remnants. This problem persists even when neutrino transport of energy from the center to higher regions in the iron core is included, as in standard simulations. The explosive energy needed to get sufficient supernova remnants for matching with observations is estimated to be about 1 foe $\equiv 10^{51}$ ergs. However, even the non-rotationally invariant models with delayed neutrino heating turn out not to provide a full one foe for the supernova explosion. Rather one typically only gets a fraction, say 1/3, of a foe. So, in order to realize a viable model for supernovae, it seems to be required that the three-dimensional or two-dimensional (meaning non-rotationally invariant) treatment should somehow bring along an extra boost reviving the shock wave. In fact no current simulation using delayed neutrino heating has produced a successful 1 foe supernova explosion [4].

So, if it were not for our pearls, there would again be the same problem that the shock wave would stall before managing to provide the explosion of the supernova. Now the revival of the shock wave by the energy available from the recombination of elements, say in the iron peak, which had earlier been split into nucleons by the shock, has recently been discussed in [4, 40]. In the usual picture, this mechanism turns out not to be so helpful for reviving the shock wave and generating an explosion with an energy of 1 foe. The problem with the usual picture is that it needs a flux of delayed neutrinos to bring the dissociated or partially recombined nucleons (e.g. to alpha particles) up from $\lesssim 150$ km in height to $\gtrsim 500$ km. However our dark matter pearls can heat up the material and/or split nuclei into nucleons all the way up to a height of 500 km. So, in our picture, energy is deposited at the height where it can help with the explosion. Also the explosions of our

pearls can easily provide energy for the revival of the shock wave. For example the shock wave would not have to split iron as it propagates, because the iron would already have been split previously by our dark matter explosion.

It is well-known that there is no supernova explosion in a rotational invariant or 1D type calculation [41] without a change in the physics. However, with the *extra energy from our dark matter balls*, even the 1D approximation *can* generate an explosion. Although, with our mechanism we do not need convection to obtain an explosion, there are reasons to believe that such convection, meaning a non-rotational invariant explosion, is there anyway.

4 Conclusion

We have previously speculated that dark matter consists of pearl-sized balls containing a different type of vacuum - one with a condensate of bound states of 6 top + 6 anti-top quarks - and very strongly compressed ordinary matter. We have here proposed that these dark matter balls can become active and suck in ordinary matter, if they become surrounded by material with a sufficient amount of free neutrons. The activity of these pearl-sized balls in a supernova consists in first of all taking in the free neutrons and thereby expanding themselves to a bigger and bigger size. Since the potential for nucleons in the vacuum inside the pearls is supposed to be 10 MeV lower for nucleons than outside, this expansion of the pearls liberates 10 MeV energy for each nucleon absorbed. The fast absorption of neutrons makes the expansion explosive and produces a large amount of energy in the region up to, say, 500 km from the center. This explosion is supposed to stop or rather postpone the usual Kelvin-Helmholtz gravitational collapse of the supernova, which begins at the end of the era of silicon burning to the iron peak elements. Before it is halted the Kelvin-Helmholtz collapse already begins to produce a bunch of neutrinos which, in the case of supernova SN1987A, was observed as the “first bunch” of neutrinos by the Mont Blanc experiment.

Then the interior of the star, heated by the explosion of the dark matter pearls, cools down by neutrino emission until the gravitational collapse can restart and generate a second bunch of neutrinos. We estimated that this would happen a period of order 14 hours after the interruption of the first collapse.

Support for our model is provided by the fact that, in the supernova SN1987A, there seemingly were indeed *two bunches of strong neutrino bursts* - each of a length of the order of 10 s. Furthermore there was an interval of 4 hours 43 minutes between the two neutrino bursts, which is perfectly consistent with our crude order of magnitude estimate of 14 hours for this delay time. A further important achievement of our model is the provision of an extra source of energy by the expansion of our dark matter pearls, which is well suited to *revive* the shock wave expelled by a newly formed neutron star. This extra energy is also able to deliver the observed 1 foe of energy needed by the stellar remnants to escape.

The dark matter pearls start out from cm-size with a density of order 10^{11} g/cm³. However, in the presence of a supply of free neutrons, the pearls rapidly expand until the (neutron) density in the surrounding material becomes sufficiently low. As the balls get

larger the electric field surrounding the balls gets weaker - although more extended - which allows the balls more easily to glue together, finally forming one big ball surrounding the neutron star.

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